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THE SCIENTIFIC BASIS OF THE ILLINOIS SYSTEM OF PERMANENT SOIL FERTILITY[1]

IT is practically impossible to cover, in an adequate way, the scientific principles underlying the Illinois system of permanent soil fertility in the brief space of time allotted me on the program. Nevertheless, I shall point out the fundamental principles underlying the system without attempting to illustrate the points made by definite data as I should like to do.

Eighty years ago Liebig, the father of agricultural chemistry, made the following statement:

> Agriculture is, of all industrial pursuits, the richest in facts, and the poorest in their comprehension. Facts are like grains of sand which are moved by the wind, but principles are these same grains cemented into rocks.

The great contribution made to American agriculture by the late Dr. Hopkins was the gathering together, classifying, interpreting and unifying, by his own investigations the known facts of agriculture, into a definite whole as practised and taught by him in the Illinois system of permanent soil fertility.

Many of the facts upon which the Illinois system rests have been known for many years and even centuries and have been developed by other men in other institutions and in other times. It remained, however, for Dr. Hopkins to bring together and unify these isolated facts into a definite workable system and by his own investigation to demonstrate clearly that the system could be understood and used by the average farmer on his own farm with very profitable results. In his interpretation of the facts upon which the system is based, all men have not agreed and some even still do not agree with him but the system rests on the

[1] An address given at the Hopkins Memorial, January 22, 1920

sure foundation of facts supported by an abundance of experimental data now available from the fields and laboratories of the University of Illinois operated under his direction.

The Illinois system recognizes clearly that there are six positive factors of crop production. These factors of crop production may be briefly indicated by single terms as the seed, temperature, moisture, light, a home for the plant, and food for its use. These factors are all of equal importance in the production of crops. Not all of the factors, however, are susceptible of equal control. It is impossible, for example, to change the temperature conditions of winter so as to make that season suitable for crop production, and the practical means available for modifying the temperature conditions of the soil during the growing period of the crop are very limited. Of all the factors of crop production, the food factor is completely within the control of the farmer. It is fully possible for him to completely change, in an economic way, the amount of food available for the plant within the soil. It is frequently true, also, that the food supply is the limiting factor of crop production, especially under humid conditions such as prevail in Illinois.

The Illinois system of permanent soil fertility, therefore, deals in a large measure with this factor of crop production. There are 10 essential elements of plant food and these are carbon, oxygen, hydrogen, iron, sulfur, calcium, magnesium, potassium, nitrogen and phosphorus. All of these ten elements of plant food are of equal importance in crop production, for, in the absence of any single one, the plant can not function normally and produce a good yield of its kind. Not all of the plant foods, however, are within the control of the farmer, while some of them are obtained from natural sources in sufficient quantities so that they never limit crop yields.

Carbon and oxygen are obtained by the plant from the small amount of carbon dioxide of the atmosphere, and this supply is constantly being replenished from natural sources. Hydrogen is obtained by the plant from the soil moisture which in turn is being constantly replenished by the rainfall under humid conditions. The plant consists largely of these elements of plant food, their compounds forming approximately 95 per cent. of all plant parts. These three elements of plant food are constantly being replenished in the soil or air from natural sources, and the farmer, therefore, need not concern himself further with them.

Iron is used by the plant in such extremely minute quantities, and the supply in the soil is so large, that it need never be added to the soil as a plant food. While the plant food requirements for sulfur are comparable in many respects with those for phosphorus, sulfur is constantly being added to the soil from natural sources in quantities more than sufficient to meet the needs of the plant for food. For these reasons, these two elements need no special consideration in a permanent system of soil fertility.

There remain, therefore, five elements of plant food which must receive careful consideration by the farmer in any system of permanent soil fertility which may be proposed. These elements are calcium, magnesium, potassium, phosphorus and nitrogen. A system which assumes to be permanent must provide for the return to the soil of those elements of plant food removed by the crop, unless they are present in the soil in unusual quantities sufficient to provide for the maximum production of crops for indefinite periods of time. The Illinois system considers and makes such provision for these five elements of plant food.

The inorganic plant foods, calcium, magnesium, potassium and phosphorus, are removed by the plants in comparatively large quantities. An ordinary rotation of wheat, corn, oats and clover would remove, for the maximum production of crops, 77 pounds of phosphorus, 320 pounds of potassium, 68 pounds of magnesium and 168 pounds of calcium, and these substances are obtained by the plant from the soil and there is no other possible source unless materials containing them are added to the soil. It is, therefore, of fundamental importance to know the amounts of these materials which occur in the soil and

to determine their relation to the requirements of the plant.

Various chemical methods have been proposed from time to time for analyzing the soil. Most of these have been based upon the fantastic claim that they determine the "available" plant food in the soil. Dr. Hopkins early realized the futility of such a claim, and concerned himself only with the determination of the total amounts of plant food within the soil. He used chemical analysis as a means of taking an invoice of these substances within the soil, just as the merchant takes an invoice of the goods upon his shelves. Whether or not the farmer makes the proper use of this material, depends largely upon him and the kind of farming he carries on, just as it depends upon the business ability of the merchant whether or not his business is successful, but in both cases an accurate invoice of stock with which he must work is as absolute a necessity for the farmer as for the business man.

The chemical analysis of the soils of Illinois, carried on with this idea in mind, soon showed a marked variation in the amounts of the various essential plant foods present in the soil. The brown silt loam of Campaign county, for example, contains over 9,000 pounds of magnesium, 10,000 pounds of calcium, 35,000 pounds of potassium, and only 1,000 pounds of phosphorus in the plowed surface soil. As measured by this accurate soil invoice, phosphorus is the most limited element in the soil, and, as measured by the crop requirements also, it is found that phosphorus is the most limited of plant foods in this typical corn belt soil. There is sufficient calcium present, for example, for the production of a 100 bushel crop of corn for 90 centuries. There is sufficient magnesium for 13 centuries, sufficient potassium for 18 centuries, while there is sufficient phosphorus for only 62 years, even if it could be utilized by the plant, and provided a maximum crop of 100 bushels of corn were produced and all material except the grain is returned to the soil. These illustrations are typical, and are very significant in emphasizing the importance of phosphorus to crop production, and indicate clearly its marked deficiency in the soil.

The fifth element, nitrogen, is very important. It is used by the plant in large quantities, and when purchased upon the markets of the world it is the highest priced of all materials. A hundred pounds of nitrogen are required for the production of 100 bushels of corn, and nitrogen at present is selling for $.30 a pound. The maintenance of the nitrogen supply of the soils is, in the language of Dr. Hopkins, "the most important practical problem confronting the American farmer." It is quite evident that the farmer can not afford to purchase commercial nitrogen for the production of his common farm crops. A tax on corn of $.30 per bushel for this purpose is absolutely prohibitive. The farmer must, therefore, depend upon legume nitrogen which is obtained by legumes such as clover, alfalfa, soybeans, etc., by the aid of symbotic bacteria from the inexhaustible supply in the air, provided the soil conditions are favorable to their growth and development. It is, therefore, necessary that a legume occur in the rotation and that the legume hay or chaff produced must be carefully conserved and returned to the soil, either as farm manure or green manure crops. It is of importance, also, that the utmost use be made of legume cover crops grown in connection with the production of wheat, and other cereals, and in the development of this use of legume cover crops the research work of Dr. Hopkins is particularly outstanding. Sweet clover was a favorite crop with him for this purpose, and he was among the first to call attention to its great possibilities. Unfortunately, legumes, so essential for soil improvement, can not be successfully grown on many soils in Illinois, as they now exist, because of the acid soil conditions which frequently absolutely prevent their growth.

A limestone soil is a rich soil, is an age old truth. Soils which have become famous everywhere for their persistent fertility are limestone soils. This is true of the soils of the far western United States, the bluegrass regions of Kentucky, the valley of the Nile, the black soils of India and Russia. Limestone,

therefore, is of fundamental importance in soil fertility. Unfortunately, limestone is easily soluble in carbonated water, and of all soil constituents probably is most readily lost in the drainage water. Humid soils, as a rule, are, therefore, deficient in this essential constituent, and the first principle of soil fertility is that limestone must be added to those soils in which it is not already present. The limestone is added primarily for the purpose of creating conditions favorable to the growth of the necessary legume crops, although it also has a markedly favorable action in increasing the yields of the cereal crops in the rotation.

There are various forms and kinds of limestone materials available for use, but the work of Dr. Hopkins has clearly demonstrated that the most economic form to use is the finely ground natural limestone—the normal material occurring in the soil. The abundance of data obtained by him on the various experimental fields for the use of finely ground limestone, particularly in southern Illinois, furnish now the best information the world affords regarding the great benefit from the use of limestone for the production of common farm crops. The addition of limestone to the soil not only corrects the acid conditions but also provides the necessary calcium and magnesium as plant foods.

In most normal soils, such as the brown silt loam of the corn belt, potassium occurs in the soil in such large quantities that it will last for the maximum production of crops for indefinite periods of time and so, in the case of potassium, the problem of the farmer is not one of addition to such soils, but is one of liberation from the insoluble compounds contained in soil. A normal soil, well supplied with fresh decomposing organic matter as provided in the grain or livestock system of farming, will provide sufficient potassium to meet the requirements of crops for this element; and the experimental results, obtained from the various experimental fields for addition of potassium, have shown clearly that it not only does not pay for itself, when used on such soils, but gives little actual increased yield.

There are certain abnormal types of soil on which potassium is absolutely essential. Such soils are peaty soils and soils deficient in organic matter. On peaty soils, potassium is the limiting element of plant food and is often the limiting factor of crop production. The addition of potassium, therefore, to such soils is an absolute necessity. On soils deficient in organic matter, such as many of those occurring in southern Illinois, potassium may be used with profitable results until the soil has been built up in its organic matter content.

On normal soils, phosphorus is frequently the limiting element of crop production. There are various forms of phosphorus available for use such as barnyard manure, steamed bone meal, basic slag, acid phosphate and raw rock phosphate. Of the various forms available, the abundant experimental data, obtained from the experimental fields maintained by the university, prove conclusively that the finely ground raw rock phosphate may be used with considerable profit and, for economic reasons, this form of phosphorus is regarded as the most desirable form to use although there may be special conditions under which some of the other forms may be used.

There are two well-defined types of farming occurring in Illinois. These are the grain system of farming and the livestock system of farming. Both of these are perfectly legitimate, proper, necessary and profitable systems of farming, and it is possible and feasible to provide means whereby the fertility of the soil may be maintained on a permanent and profitable basis in either case. Both types of farming are absolutely necessary and essential to the development of the highest stage of civilization, for as long as man demands bread, butter, meat and milk, and until we are willing that our standard of living shall be lowered, both of these types of farming must exist. It is essential, therefore, that provision be made whereby the fertility of the soil may be maintained in order that grain and livestock farming may become permanent institutions in the land. The Illinois system of permanent soil fertility recognizes this fact, and makes provisions for the maintenance of

fertility on both the livestock and the grain farm. In either type of farming, limestone and phosphate must be used so as to permit the growth of legumes so essential in soil improvement and also in the feeding of livestock.

While Dr. Hopkins took particular pains to point out and emphasize the possibility of maintaining the fertility of the soil on the grain farm on a permanent and profitable basis, he also made important contributions to our knowledge regarding methods of maintaining the fertility of the livestock farm. The teachings of Dr. Hopkins in this respect are of tremendous importance since they provide for the extension of livestock farming to large areas where heretofore the proper feeds could not be produced. On all of the experimental fields just one half of the work is devoted to the maintenance of soil fertility in livestock farming. The livestock farmers of Illinois should have a deep sense of gratitude to Dr. Hopkins for his work in their behalf.

If a system is to be permanent, the materials removed from the soil must be returned, at least in the proportion in which they are removed by natural processes, including the amount removed by the crop and the amount lost in the drainage water. This would seem to be such a simple axiomatic truth that it need not be dwelt on; however, it is a point which must be constantly emphasized again and again. The use, therefore, of two or three hundred pounds of an ordinary commercial fertilizer of a 2-10-2 grade, which adds only five or six pounds of nitrogen, must act purely as a soil stimulant. For, if increased crops are obtained by its use, they can be obtained only at the expense of the nitrogen already in the soil, since the requirement for a 100 bushel crop of corn is 100 pounds of nitrogen. The Illinois system of permanent soil fertility, therefore, condemns in unmeasured terms the use of such soil stimulants, among which must be classified ordinary mixed commercial fertilizers and gypsum.

In the briefest way possible, the very essential points underlying the Illinois system of permanent soil fertility have thus been merely touched upon. But it is the desire to emphasize at this point that the Illinois system of permanent soil fertility rests upon a sane and safe scientific basis, and, because it makes abundant use of cheap, natural, raw, products, as legume nitrogen and finely ground materials such as limestone and rock phosphate, it is both a permanent and profitable system of soil fertility. This is the heritage to Illinois farmers left by him in whose memory we have met here to-day.

ROBERT STEWART
UNIVERSITY OF ILLINOIS

RADICALISM AND RESEARCH IN AMERICA

INVESTIGATORS who are concerned as to the possibility of adequate facilities for research being maintained by popular governments, or who doubt whether a republic working through democratic institutions like our National Research Council can equal the scientific attainments of autocratic Germany, will derive much encouragement from a review of American history. Prominent among the agencies which, in addition to privately endowed institutions, have supported the prosecution and publication of scientific research in this country are Academies of Science, State Universities, Land Grant Colleges and Agricultural Experiment Stations, Federal Department of Agriculture, Coast and Geodetic Survey and the State and National Geological Surveys. In many cases the inception or period of most marked development of these institutions has been closely linked with striking political developments. Without presenting any unpublished data the present paper aims to assemble some of the facts which seem significant in this connection.

Undoubtedly the most radical document ever adopted by an American national assembly was the Declaration of Independence. The active members of the committee appointed to draft this instrument were Franklin, Adams, and Jefferson, each of whom made a distinct contribution to the advancement of scientific foundations in America.

Franklin's fame as a scientist, as a diplomat, and as leader of the radical faction in our